# Target diagnostics

Orion provides a comprehensive suite of target diagnostics to try and understand the plasma conditions created through the laser interaction on a millimetre-scale target positioned at the centre of the Orion target chamber. Some of these diagnostics are mounted in one of six Ten-Inch Manipulators (TIMs) and experimental teams can have access to those instruments without needing to break the vacuum on the target chamber. Many more instruments are mounted directly onto the target chamber.

The principal diagnostics fielded on Orion are:

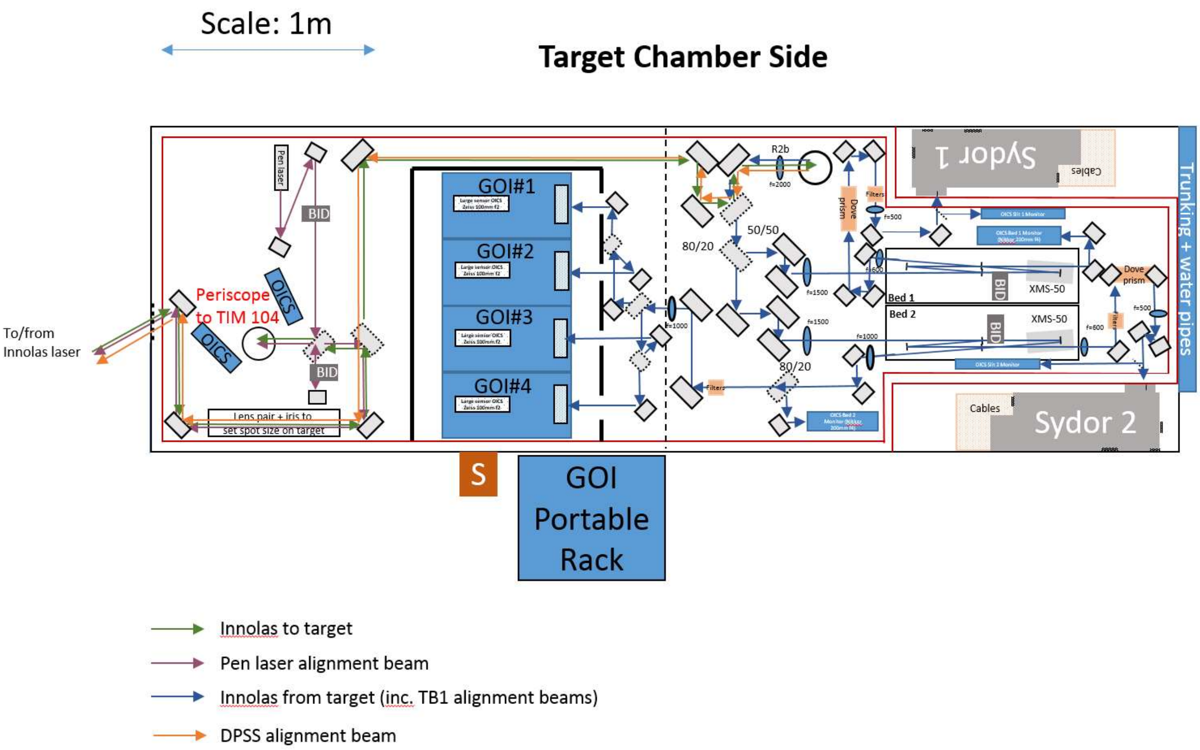
# Optical

## VISAR

Twin Mach-Zehnder interferometer beds with different etalons (different VPF) to reduce fringe shift ambiguities

Nd:YAG probe laser (532nm)

Line-imaging velocity interferometry (Sydor optical streak camera) and 2D snapshots using GOI (Gated optical Imager)

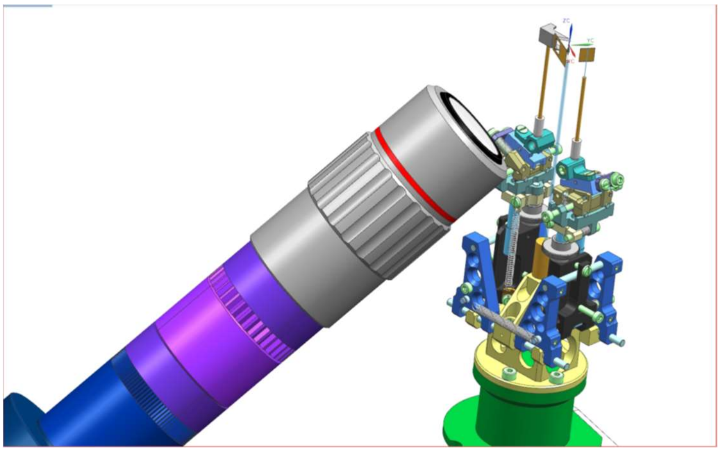



As designed, the collection optics can potentially be fielded in one of three (out of the six) Orion TIMs, although most experience has been gained with the axial TIM (TIM 104).

## Streaked Optical Pyrometry

Designed to deliver broadband "brightness temperature measurements of low (1-10eV) temperature sources. Time resolution of about 4 ps is achieved at ORION through the use of a highly sensitive Axis Photonique streak camera with a P820PSU streak tube. The streak camera is located over 8 m from the target chamber centre: optics relay an image of the target to the streak camera with no vignetting over a 0.4 mm field of view with 12.5x magnification.

All lenses in the system are diffraction limited and apochromatically corrected to allow high resolution imaging over a broad spectral range. High light collection efficiency is achieved through the use of an f/1.4 objective, and a minimum number of reflecting and refracting surfaces. Divergence, and therefore vignetting of the highly magnified image is limited by a tube lens relay rigidly held behind the objective.

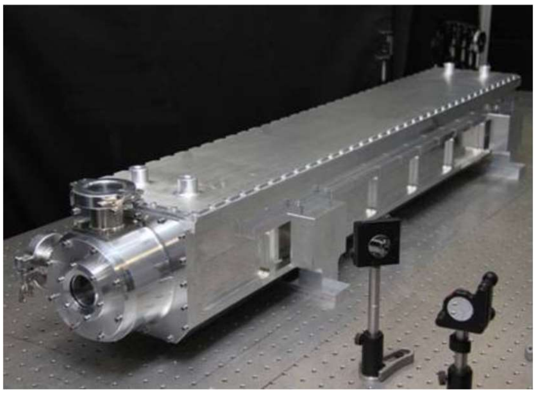


## X-Ray

**Streak Cameras (TIM-compatible)**

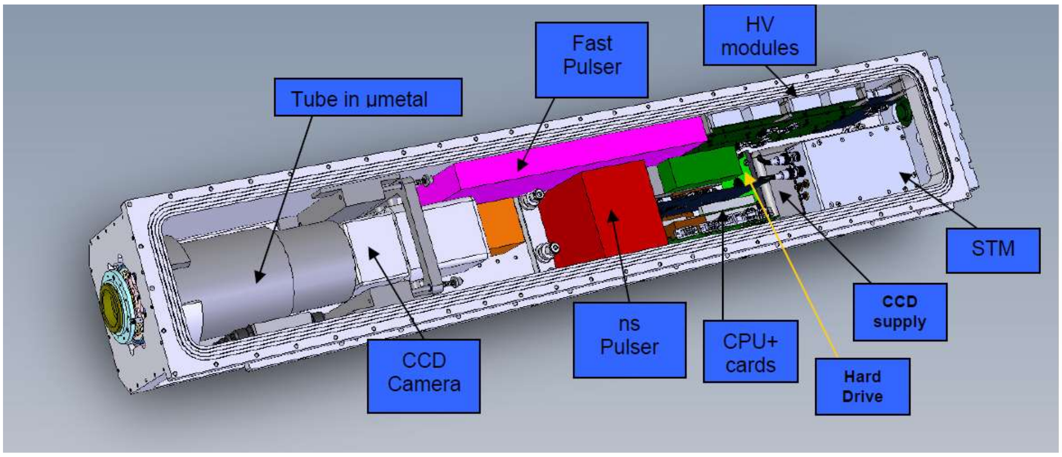
The X-ray Streak Camera (XRSC) provides a means of time-resolving the laser-plasma interactions at picosecond resolutions. There are a total of four XRSCs used with the TIM diagnostic insertion system. Two of them are "picosecond" cameras, with 200 ps, 500 ps, 1ns and 2 ns sweep ranges, and the other two are "nanosecond" cameras, with 5 ns, 10 ns, 25 ns and 50 ns sweep ranges. The picosecond XRSC has a resolution of < 1 ps, and the nanosecond XRSC a resolution of a few ps.

When used in real shot configuration, the XRSCs communicate via an Ethernet over fibre optic connection. Each camera has its own address on the Orion control network. The Orion control system sends the setting parameters to each camera, requests their status, and tells them to standby for the laser shot. After the shot, the control system retrieves the raw images and shot data from each camera for further analysis.



TIM-compatible X-ray Streak Camera

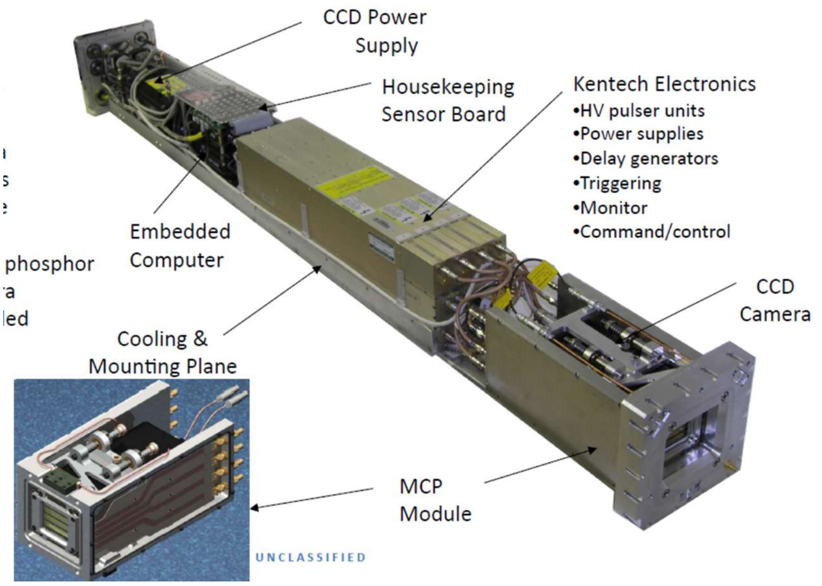
| Specification |
| --- |
| TIM based<br>Power input: 24 Vdc<br>Communication: Ethernet over fibre optic<br>**Sweep ranges:**<br>Picosecond cameras: 200 ps, 500 ps, 1 ns and 2 ns<br>Nanosecond cameras: 5 ns, 10 ns, 25 ns and 50 ns<br>**Limiting temporal response:**<br>Picosecond cameras: 1 - 4 ps<br>Nanosecond cameras: 8 - 100 ps<br>Weight: < 60 kg |



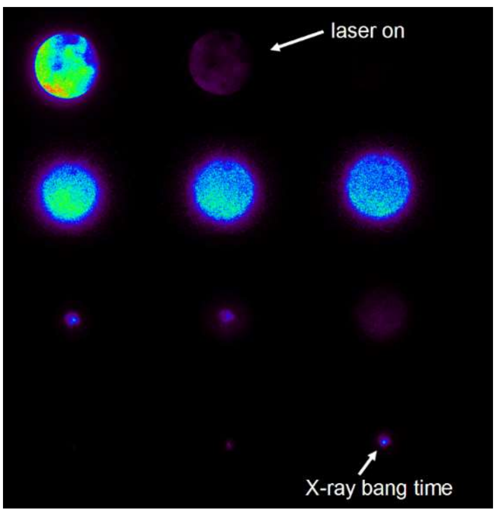

TIM-compatible X-ray Streak Camera

**Gated X-ray Detector**

The Gated X-ray Detector (GXD) uses Micro-Channel Plate (MCP) technology to provide 2D spatially resolved, time gated images of X-ray emission. The airbox assembly was designed by the Los Alamos National Laboratory (LANL) in the USA and is used on Orion to record X-ray images and spectra from laser-irradiated targets. The diagnostic includes an electronic support system, MCP detector head, MCP drive electronics, and Charge Coupled Device recording of the phosphor image. The diagnostic is designed to operate in a TIM, and is mounted in an 'airbox' which allows the electronics to operate without overheating whilst the device is in the vacuum chamber. 3 separate GXDs are available.Various diagnostic packages can be used as the front-end assembly. Number of images depends on snout:  pinhole cameras with: 3x, 5x, 10x and 20x mag.; slit imaging spectrometer; open (point projection) snout, and the detector head (3 4-strip, 1 2-strip, 1 1-strip head are available)



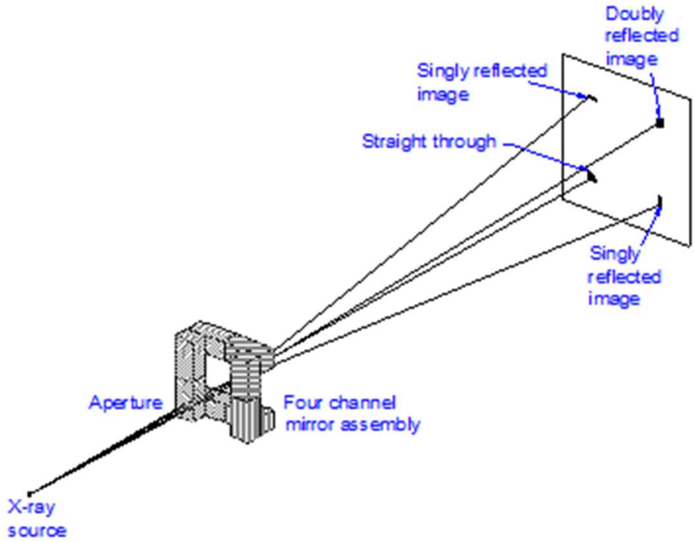

Gated X-ray Detector electronics



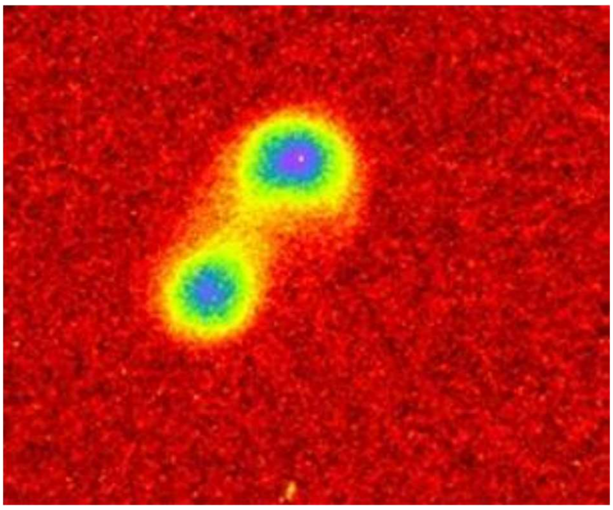

| Specification |
|---|
| TIM based<br>Power input: 24 Vdc<br>Spatial response: 0.01 - 10 keV<br>Temporal response: ≤ 100 ps - 2 ns<br>No. of independent strips: 1 , 2 or 4<br>Dimensions (LxWxH): 1481 x 173 x 167 mm<br>Weight: 54.9 kg |

**KB X-ray Microscope (KBXRM)**

The KB X-ray Microscope (KBXRM) used on Orion is an imaging system with a large field of view and high spatial resolution. It is designed to confirm beam pointing on a shot-to-shot basis and recording the 2D time-integrated images on electronic detectors. The microscope allows assessment of laser spot size, shape, structure and position, and achieves this by using pairs of spherical grazing angle mirrors in the Kirkpatrick-Baez (KB) geometry. Two microscopes are used in the Orion Target Chamber providing time integrated images of the X-ray emission from the target. They are sensitive to emissions in the photon energy range 100 eV to 3 keV and are capable of imaging X-rays at high resolution: better than 10 µm in the centre, and better than 35 µm at the edge of the 2 mm field of view.




Kirkpatrick-Baez microscope geometry

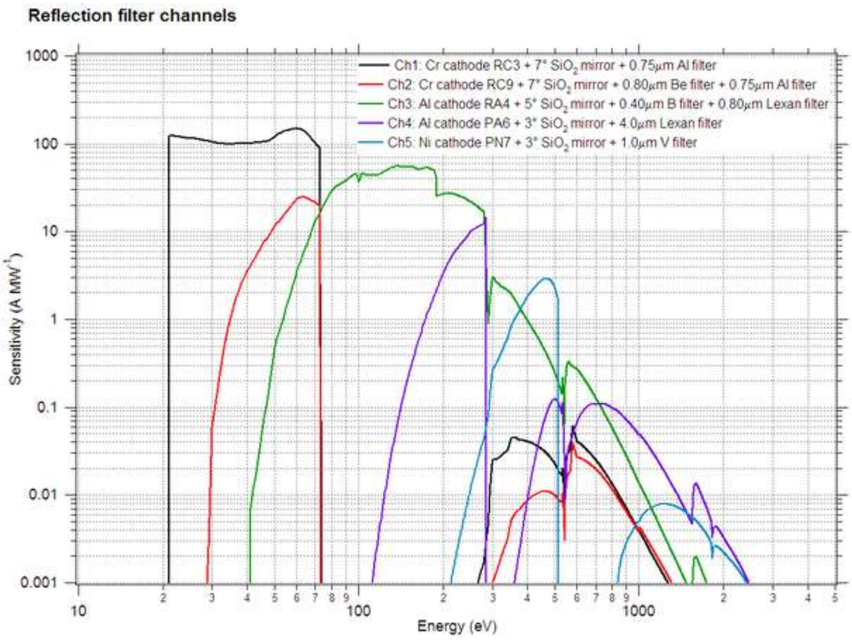


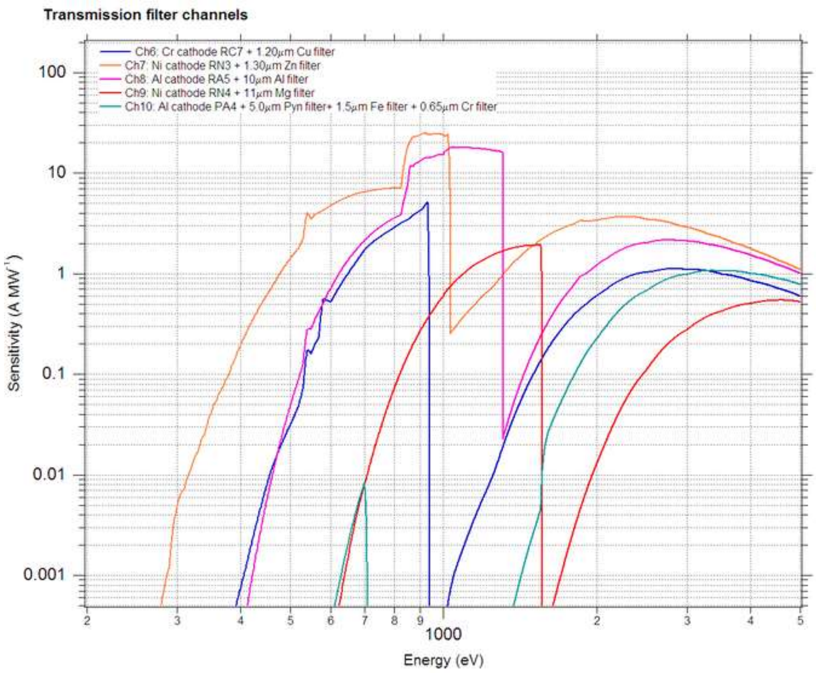
Example data

| Specification |
| --- |
| Spectral range: 100 eV to 3 keV<br>Field of view: 2 mm<br>Resolution: Across field of view > 35 µm<br>At centre of field > 10 µm |

**Dante**

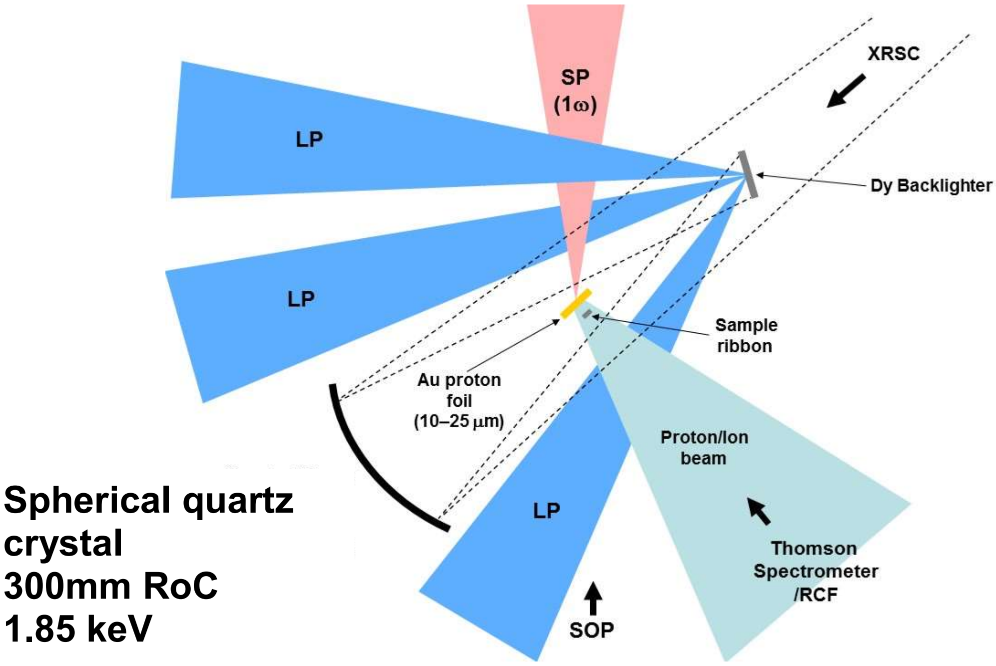
The Dante measures the absolute X-ray energy emitted from a laser-target interaction to enable a calculation of the target temperature to be achieved. This is the primary diagnostic of most high-power laser facilities since the purpose of the laser in all experiments is to heat the target. The laser-heated target typically reaches temperatures of > 100 eV, and therefore emits an approximately black-body spectrum in the X-ray region of the electromagnetic spectrum. The Dante diagnostic provides a relatively simple design principle that can be thoroughly calibrated to reliably measure the soft X-ray emission (0.1 - 5 keV). The principle behind the Dante X-ray flux measurement is to run a number of detectors in parallel, but filter the X-ray emission they measure, so that they are sensitive to different regions of the emitted spectrum. A mathematical unfold process is then used to estimate the signals measured by each detector for a given spectrum, and then iterate closer to the measured signal level. In this way it is possible to measure the spectrum and temperature of the X-ray source.

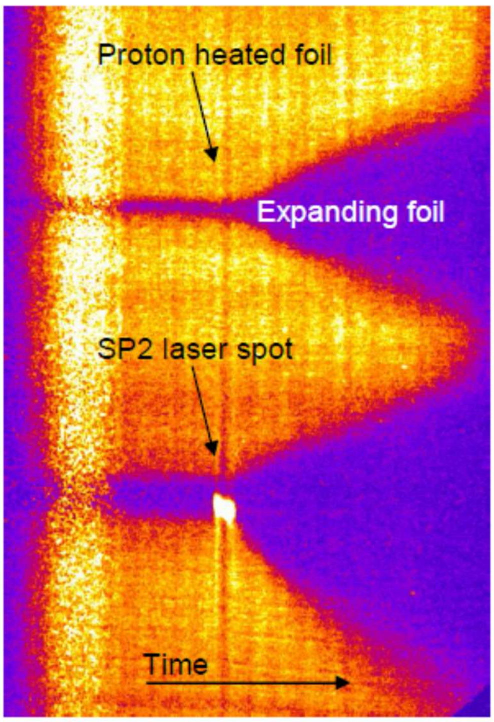


**Monochromatic X-ray Imager:**

This system provides high resolution monochromatic imaging via a spherical crystal, mounted in a TIM payload, and a detector mounted outside the target chamber wall; either an X-ray sensitive CCD camera or, more typically, an X-ray streak camera.

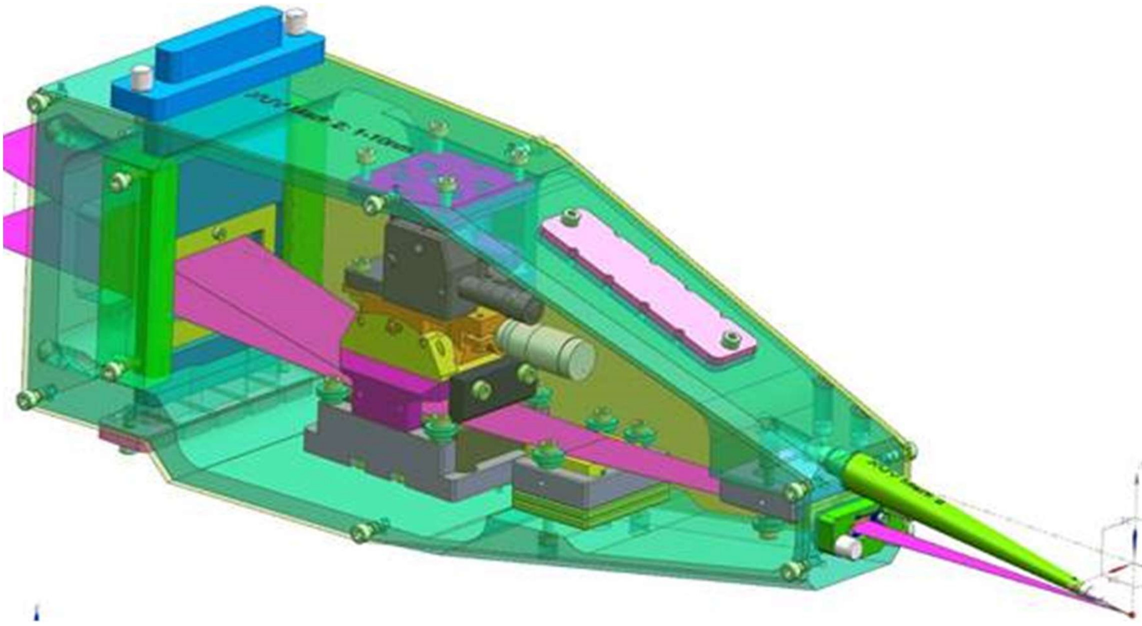



*Streaked MXI image of a proton-generating foil (bottom) and its proton-heated counterpart (top)*

**XUV Grating Spectrometer:**

A soft X-ray diagnostic, making spectrally resolved measurements of the radiation produced in laser-plasma interactions in the range of 1-40 nm with a high spectral resolution (~1000). The spectrometer is deployed inside an Orion TIM and interfaces with X-ray Streak Cameras, Gated X-ray Imagers or Soft X-ray Charge Coupled Detectors. Interfacing with an X-ray streak camera, allows the emission to be temporally resolved, with the temporal resolution defined by the sweep speed of the camera.



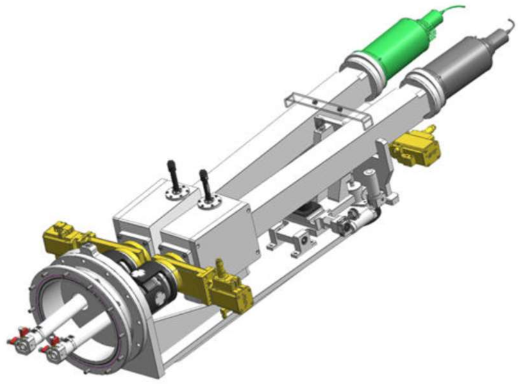
Overview of the 1-10nm XUV Grating Spectrometer head (with alignment pointer attached)

The XUV Grating Spectrometer has the option to use one of two diffraction gratings, providing the dispersive element in the range of 1-10 nm and 10-40 nm to provide the required spectral resolution across the 1-40 nm range.

| Specification |
| --- |
| TIM based<br>Spectral range: 1 - 40 nm<br>Spectral resolution: ~1000<br>Diffraction gratings: 1 - 10 nm and 10 - 40 nm |

**Transmission Grating Spectrometer**

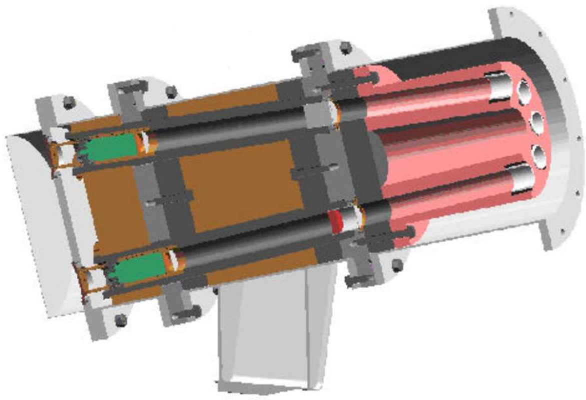
The Transmission Grating Spectrometer (TGS) is permanently mounted on the Orion Target Chamber. It is used to measure absolute spectral intensity from targets in the 10 - 100Å (0.12 - 1.2 keV) spectral range with 10 % accuracy. The purpose of the TGS is to complement the Dante, a filtered diode array soft X-ray power diagnostic, with the potential to achieve higher temporal and spectral resolution. The instrument consists of two independent transmission grating spectrometers consisting of a collimating aperture, a thin filter, a 0.5 mm period transmission grating and a detector that views the target along closely-coupled lines-of-sight. One spectrometer disperses the incident spectrum along the slit of a high time resolution electron-optic streak camera. Although the streak camera is capable of high time resolution (~10 ps) it is difficult to absolutely calibrate for input flux owing to the build-up of errors in the instrument sub-components. To provide absolute flux calibration a second spectrometer uses a soft X-ray sensitive Charge Coupled Detector (CCD) with radiometric calibration. The X-ray sensitive CCD provides time integrated spectral information. Combining the data from both spectrometers permits the absolute time resolved spectrum to be unfolded.



| Specification |
| --- |
| Spectral range: 0.12 - 1.2 keV<br>**Grating specification**<br>Material: Gold<br>Thickness: 0.5 µm<br>Grid: 20 x 20 µm<br>Source-grating distance: 2500 mm<br>Grating-detector distance: 555 mm<br>Grating period: ~5200 Å<br>Slit width: 70 µm<br>**Streak camera specification**<br>Spectral range: 10 - 100 Å<br>Dispersion: 9 Å $mm^{-1}$<br>**X-ray CCD camera specification**<br>CCD full well capacity: 147,500 electrons<br>Pixel size: 13.5 x 13.5 µm |

**Hard X-ray Spectrometer**

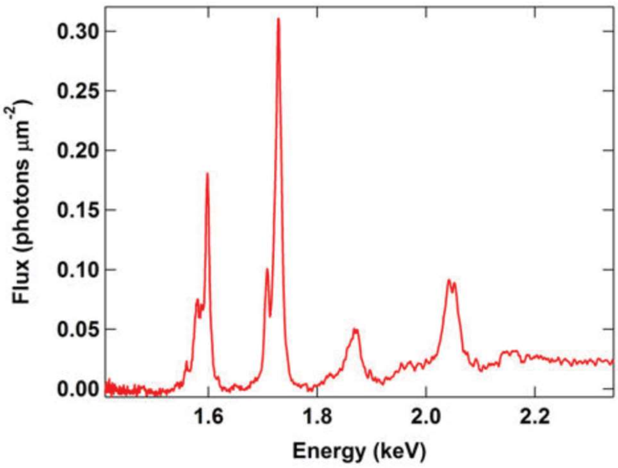
The Hard X-ray Spectrometer (HXRS) has an array of filtered detectors that provide a time integrated measurement of the hard X-ray spectrum relevant to ultra-high intensity interactions, and includes time resolution for discriminating against background signals. The spectrometer includes remote control of essential features such as high voltage bias supplies and is designed to survive in the radiation environment generated by short-pulse laser-plasma interactions. The HXRS provides an absolute, time-integrated measurement of the hard X-ray spectrum. The purpose of the HXRS is to derive the hot electron temperature by measuring the hard X-ray radiation (100 keV - ~2 MeV) produced by laser-irradiated targets. In order to detect the hard X-ray spectrum, each HXRS channel detector consists of a filter, scintillator and a Photomultiplier Tube (PMT). The spectral response of a given channel is determined by the choice and thickness of the filter and the scintillator, in addition to the hard X-ray spectrum intensity. X-rays transmitted by the filters are absorbed by a scintillator material that converts X-rays into visible photons. The scintillator absorption determines the HXRS channel cut-off at high X-ray energies. Conversion of the weak light output of a scintillation pulse into an electrical signal is achieved using PMTs.



| Specification |
|---|
| Number of channels: 8<br>Spectral range: 100 keV - ~2 MeV |

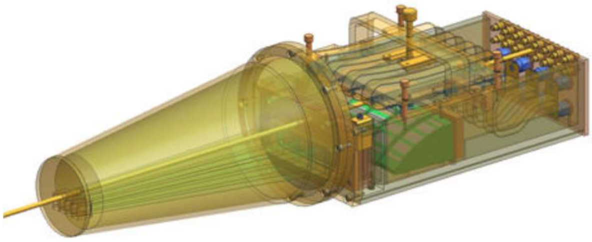
**Time-integrating X-ray Spectrometers**

X-ray film spectrometers use crystals to disperse X-rays in a variety of geometries to give the X-ray spectrum relevant to an experiment. The spectrometers used on Orion are all deployed in an Orion TIM. A number of spectrometers are used in Orion: Twin Crystal Spectrometer; Horizontal Belfast Spectrometer; Vertical Belfast Spectrometer; Precision Orientation Spectrometer; and Time Integrated Focusing Spectrometer.  Crystal choice and angular range gives 1-10keV at moderate resolution (E/dE~1000)



**High-Energy X-ray Spectrometer (HEX-ID)**

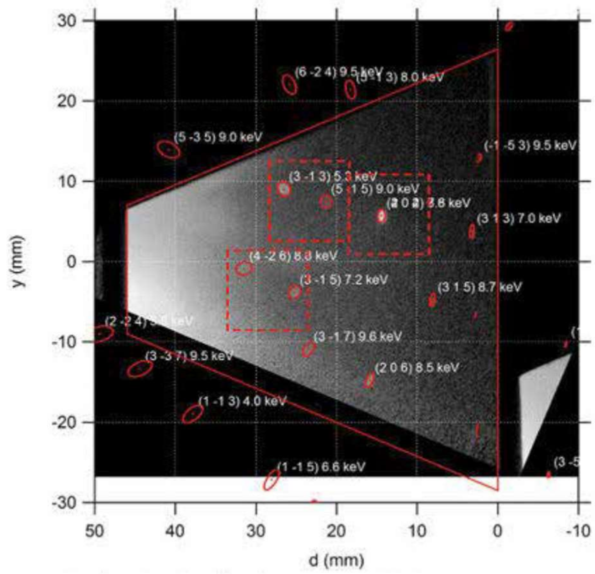
The High-Energy X-ray Spectrometer (HEX-ID) is a TIM based diagnostic that is fielded on both short-pulse and long-pulse laser shots and has a spectral range of 1 keV to 10keV. The diagnostic provides very high resolving power soft X-ray spectroscopy, soft X-ray fluxes originating from laser-plasmas and high temporal resolution measurements of X-ray emissions to enhance plasma diagnosis for Orion laser experiments. The diagnostic provides data on plasma opacity, detailed analysis of characteristic X-ray spectra from backlighter materials, identification of plasma ion species and absolute measurement of laser to X-ray conversion efficiencies. The diagnostic includes interchangeable detectors to allow spatially and/or temporally resolved measurements in the same laser shot. It is provided with shielding against electromagnetic pulse interferences generated in short-pulse laser plasma environments and is designed around a convex reflection crystal system. There is a choice of three types of X-ray detector: image plate, complementary metal oxide semiconductor (CMOS) sensor or diamond photo-conductive detector (PCD) (in six modules). A filter stack is located next to entrance aperture to define spectral range and flux for each channel.



| Specification |
|---|
| TIM based<br>Resolving power: E/δE~800<br>Spectral range: 1 - 10keV<br>Alignment laser: Class 2, 0.9mW, 655nm red laser |

**Broad-Band X-ray Diffraction Diagnostic (BBXRD)**

The Broad-Band X-ray Diffraction Diagnostic (BBXRD) is a small, passive, device that is deployed in an Orion TIM. It is a type of Laue camera used to record X-ray diffraction data from single-crystal samples of different materials (typically crystals of silicon, iron and tantalum). The diagnostic consists of a pyramid-shaped enclosure containing X-ray imaging plates mounted internally at its four sides and one or more single-crystal samples mounted from its square base. X-ray radiation from a laser-illuminated target enters the smaller end of the diagnostic enclosure through a collimating pinhole or slit, and propagates along the axis of the enclosure to the crystal sample. Diffracted radiation is recorded by the imaging plates.

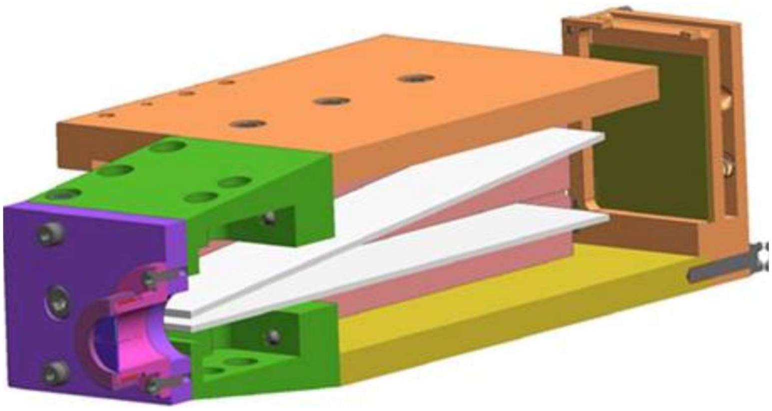



| Specification |
| --- |
| TIM based |
| Positional alignment accuracy: < 500 µm |
| **Dimensions** |
| Uni-mount to TCC: 273 mm |
| Front to TCC: 40 mm |
| Large end: 65 x 65 mm |
| Small end: 30 x 30 mm |
| Length: 50 mm |

## Particle

**Thomson Parabola**

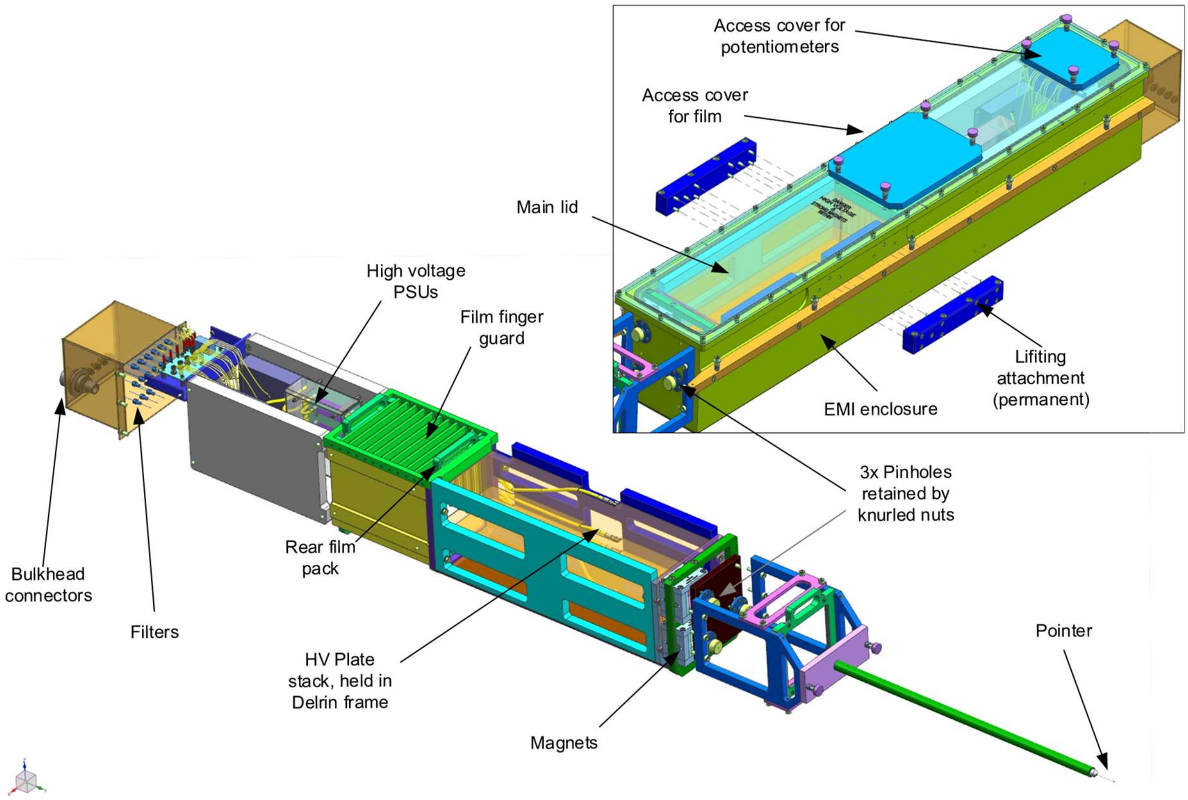
The Thomson Parabola is a charged-particle-discrimination spectrometer used to record charged particle spectra generated by Orion during laser-plasma interactions. It is deployed in one of the TIMs attached to the Target Chamber. The Thomson Parabola employs parallel electric conducting plates held at a potential of several kilovolts to disperse ions by charge-to-mass ratio and a matched pair of permanent magnets to orthogonally deflect moving ions to provide velocity-based dispersion. The diagnostic uses CR39 as a detection medium, mounted in a cassette at the rear of the device. Ions of a particular species form a series of pits ~20 µm in diameter in the CR39, dispersed by energy along a parabolic shape. The CR39 is then processed to reveal the ‘tracks’ from which the energy and species of the ions can be measured. Both a single channel and a multi-channel device are available.



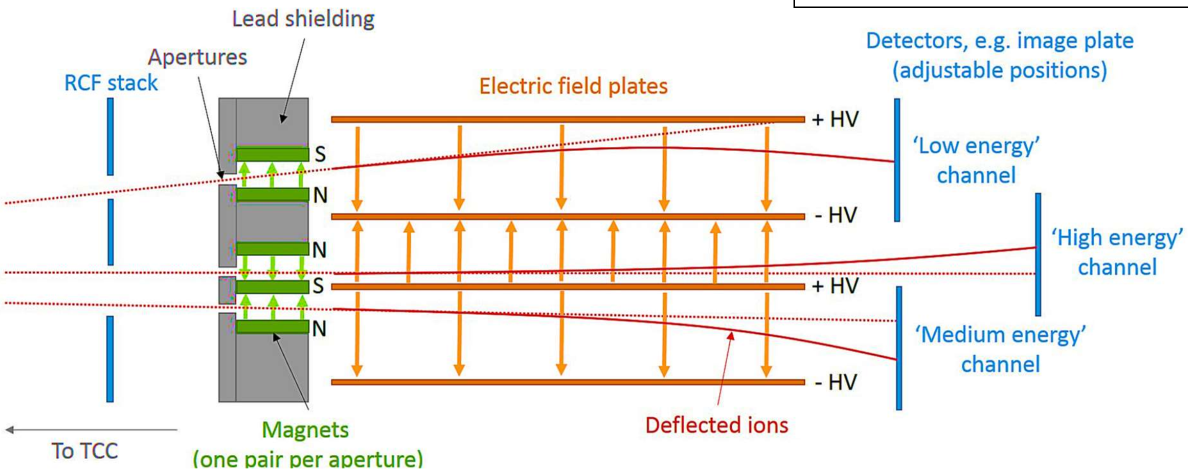
| Specification |
| --- |
| TIM based<br>Applied voltage: 1.6 - 10 kV<br>Magnetic field strength: 0.15 or 0.78 T<br>Energy range (protons): 100 keV - 10 MeV<br>Detector material: CR-39 |

Single channel Thomson Parabola

**Multi-channel Thomson Parabola**



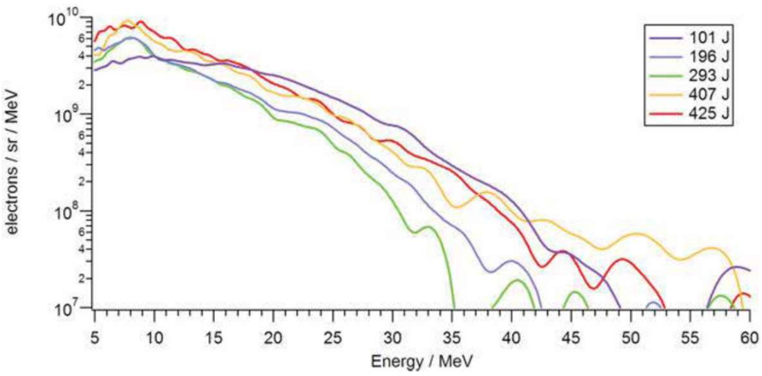

| Specification |
|---|
| TIM based<br>Applied voltage: 1.6 - 10 kV<br>Magnetic field strength: 0.15/ 0.8 / 1.0 T<br>Energy range (protons):<br>200 keV – 1 MeV Low<br>1 – 20 MeV Mid<br>5 -100 MeV High<br>Detector material: CR-39 |



**Electron Positron Proton Spectrometer (EPPS)**

The Electron Positron Proton Spectrometer (EPPS) is an LLNL designed instrument that is fielded on Orion. It is a TIM-based charged particle spectrometer that uses permanent magnets generating an internal magnetic field of approximately 0.8 T. The magnetic field spreads out incoming particles, which then strike one of two image plates depending on their charge.

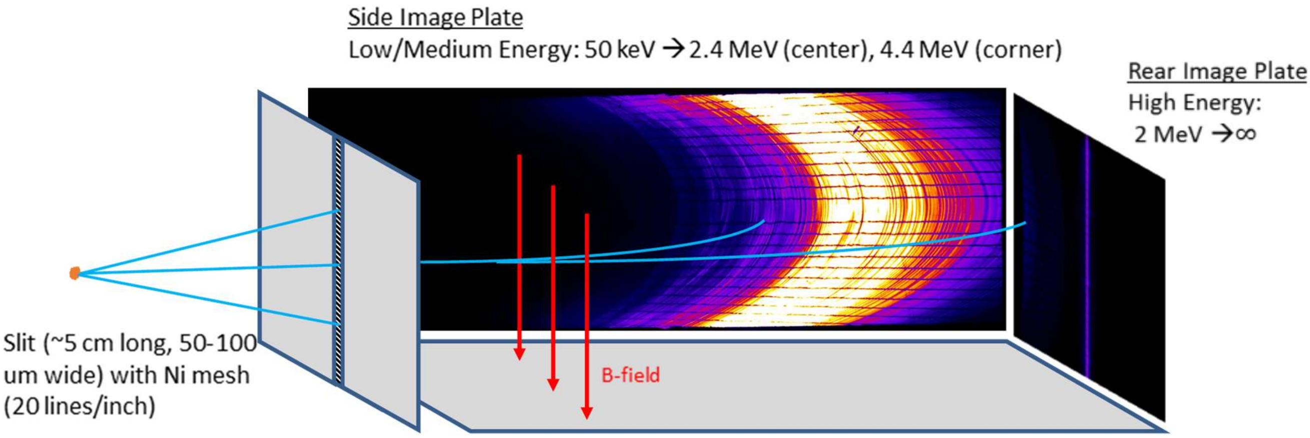
The EPPS weighs approximately 39.5 kg and therefore requires lifting aids. The diagnostic does not require power, chilled water, timing or communications. All materials are vacuum compatible and the alignment method utilises a removable ruby tipped pointer. The EPPS can be used in TIM44 or TIM104 directly opposite one of the short pulse beam parabolas.




| Specification |
|---|
| TIM based<br>Magnetic field: 0.8 T<br>CofG to TCC: 751 mm<br>Image plates: Fuji - SR-2040<br>Weight: 39.5 kg |

**Imaging Proton Spectrometer**

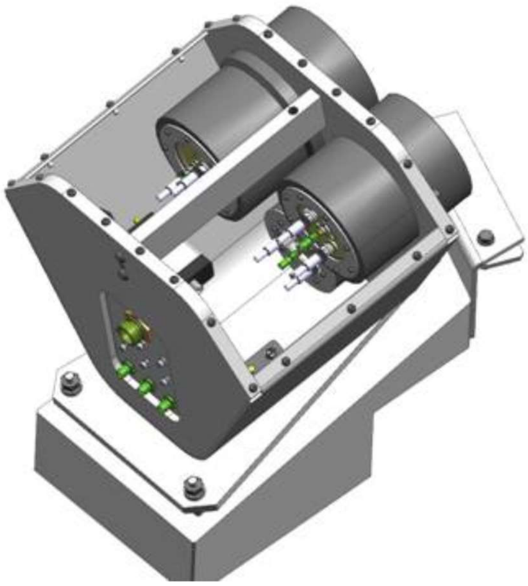
The Imaging Proton Spectrometer (IPS) is an LLNL designed instrument that is fielded on Orion. It is a TIM-based charged particle spectrometer that uses a magnetic field to disperse the proton spectrum, in conjunction with a slit images the source to provide spatial information.




*H. Chen, A. U. Hazi, R. van Maren, S. N. Chen, J. Fuchs, M. Gauthier, S. Le Pape, J. R. Rygg, and R. Shepherd, RSI* ***81****, 10D314 (2010).*

**Neutron Time-of-Flight (nToF)**

The Neutron Time-of-Flight (nToF) system measures the neutron energy spectrum generated during laser-plasma interactions, for yields between $2x10^7$ and $10^{11}$ neutrons. The nToF system works in a harsh environment of energetic neutrons, X-rays, gamma rays, and high Electromagnetic Pulse noise. The nToF diagnostic consists of three separate detectors with different scintillator configurations in order to cover the range of possible neutron yields. Neutrons are captured in the scintillator and converted to visible light which is guided into a Photomultiplier Tube that converts the optical signal into an electrical one. The electrical signal is transmitted to and displayed on an oscilloscope. The Full Width Half Maximum of the signal is used to infer the ion temperature and the area under the peak is used to infer Total Neutron Yield. The nToF diagnostic is located outside the Target Chamber 5.6 m from the target, providing a means of discriminating neutrons of different energies through their time of flight. Time resolving the arrival of the neutrons allows you to get an accurate spectrum of the neutron energies. A 5.6 m flight path is adequate for ion-temperature measurements.



**Neutron Total Yield**

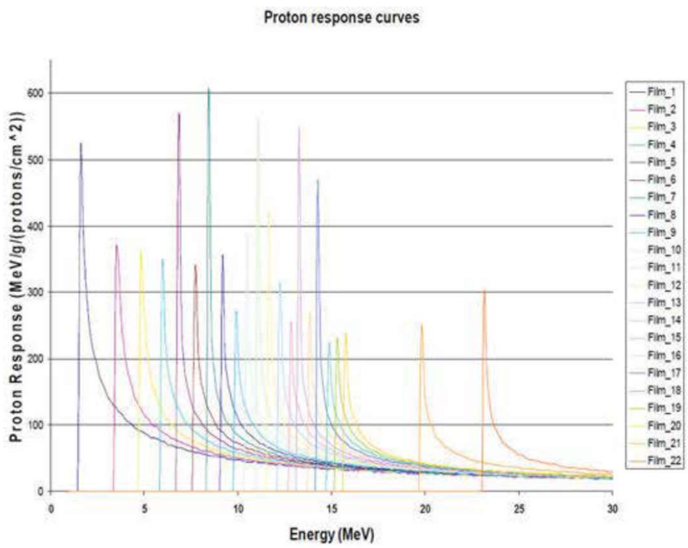
The Neutron Total Yield diagnostic on Orion uses a pneumatic transfer system to transport irradiated copper sample material in a timely manner from the Target Chamber to the Nuclear Physics Laboratory. This method for recovering the sample ensures the irradiated material is delivered to the Nuclear Physics Laboratory with as little delay as possible. The system includes a sliding sleeve send/receive terminal located in Orion Nuclear Physics Laboratory and tube that extends to the Target Chamber and terminates at a re-entrant tube. The system is supplied with three re-entrant tubes having different carrier assembly ‘rabbit’ stopping positions. The picture below shows a ‘rabbit’ with a copper sample installed. Infers the neutron signal from the experiment using irradiated copper sample material, and induced activation and reaction cross sections.

The method used for measuring the neutron yield during an indirect drive Deuterium-Tritium implosion is to let the 14.1 MeV neutron signal emitted during the reaction activate a piece of copper placed close to the experiment, and then infer the neutron signal from the induced activation and the reaction cross section. The 63 Cu(n,2 n)62 Cu reaction has a threshold of 11 MeV and a beta+ decay half-life of 9.74 minutes. If one measures how much activity is induced in the copper and the efficiencies of the complete counting system, the number of neutrons originally interacting with the copper can be recovered.

| Specification |
| --- |
| Sample material: Copper or Indium |

**CR-39 Detector**

The CR-39 Detector is deployed in an Orion TIM and is used to record protons up to 13 MeV. CR-39 is transparent in the visible spectrum and is almost completely opaque in the ultraviolet range. CR-39 has the chemical formula $C_{10}H_{18}O_7$, is about half the weight of glass (density of ~1.30 gcm$^{-3}$) and is resistant to most solvents and other chemicals, gamma radiation, aging, and to material fatigue. In the radiation detection application, raw CR-39 material is exposed to incident ions and/or neutrons. CR-39 will record particles with $Z/\beta \geq 6$ where β is the relativistic velocity meaning it will record protons up to 13 MeV. A charged particle entering the plastic will be bought to rest by losing energy through ionization, damaging the polymer. An ion needs to have a minimum of ~75 keV to cause this damage. The damage manifests as 'tracks' through the material which are enlarged by an etching process in a ~80 °C bath of sodium hydroxide. The enlarged ion tracks are counted under a microscope (magnification ~100×), and the number of ion tracks is proportional to the amount of incident radiation. The tracks for heavy ions and protons are quite distinctive under microscopic analysis, so can yield useful information about the ionic species present.

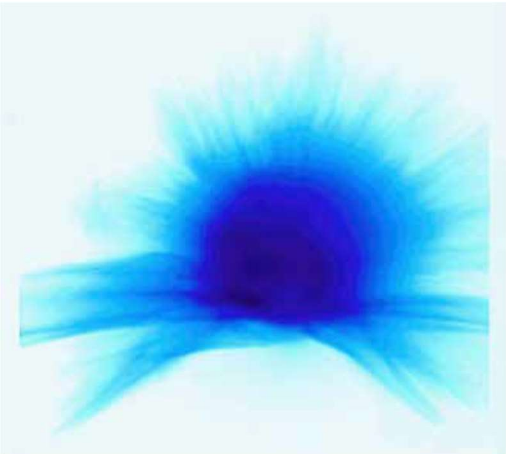



| Specification |
| --- |
| TIM based<br>Detector material: California Resin Type 39 (CR-39)<br>Dimensions of detector: 50 x 50 mm or 100 x 100 mm<br>Proton/ion energy range: 0.75 - 13 MeV |

**Radiochromic Film (RCF)**

Radiochromic film (RCF) is deployed in an Orion TIM and is used to diagnose the protons and ions produced in ultra-high intensity laser-plasma interactions. Radiochromic film is a light blue, clear, translucent plastic film that darkens on exposure to ionising radiation. It is only weakly sensitive to visible light. The major uses are medical applications such as measuring dose in radiotherapy – medical literature reports the colour change is largely independent of proton energy and has a near linear dependency to fluence. RCF is typically deployed in \`stacks' in combination with filters such as aluminium foil and can also be used in conjunction with CR-39 to diagnose the protons and ions produced in laser-plasma interactions. It is also used for radiographs and transient electromagnetic field detection. It has high spatial resolution (~1 µm) and can offer limited temporal resolution as higher energy protons will probe earlier times. A stack typically consists of an initial layer of aluminium to block out visible radiation and the majority of X-rays. Multiple layers of RCF are then used - the higher the proton energy, the greater its range in the stack. Hence, the whole energy spectrum can be unfolded into energy bins. Often a stack will have 'spacers' with a higher stopping power such as copper (also used for activation measurements) or CR-39 to reduce the number of layers of RCF required to observe the highest energy protons. By attributing a specific layer a given energy, the fluence can be calculated from the measured dose.

**Raw Exposed Radiochromic film**



| Specification |
|---|
| TIM based<br>Detector material: Radiochromic film<br>Dimensions of detector: 50 x 50 mm or 100 x 100 mm<br>Proton/ion energy range: > 0.5 MeV |